AN INVESTIGATION OF PHYSIOLOGICAL CORRELATES OF VIGILIANCE PERFORMANCE

James Hager Tinsley

United States
Naval Postgraduate School

THESIS

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October 1969

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An Investigation of Physiological Correlates of Vigilance Performance

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James Hager Tinsley
Major, United States Marine Corps
B.S., United States Naval Academy, 1959

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
October 1969

ABSTRACT

A pilot investigation of physiological parameters was conducted to determine possible correlates of vigilance performance. Six parameter measurements were continuously recorded during a forty-eight minute vigil as six subjects monitored a voltmeter display. Simple and multiple linear correlation analyses were performed to determine the relationship between parameters observed and the percentage of signals detected. Results showed systolic blood pressure ($r = .382$, $p < .08$), skin temperature ($r = .378$, $p < .08$), and diastolic blood pressure ($r = .330$, $p < .13$) were each correlated with vigilance performance. No correlation was found between performance and skin resistance, heart rate, or pulse pressure. A multivariate analysis indicated that the addition of skin temperature to systolic blood pressure provided a multiple correlation of $R = .497$, $p < .06$, between those parameters and performance, and the further addition of pulse pressure as a third variable increased R to $.541$, $p < .08$. These results and some additional, ad hoc analyses are interpreted in the context of the Arousal Theory of vigilance.

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I. THE PROBLEM

A product of our civilization's tremendous technological advances has been the replacement of man by machines for the performance of many tasks. Frequently, these newly automated jobs require man to observe a variety of instrumentation to indicate the status of the operation and to initiate changes to the system when required. Further, technology has produced new mechanisms capable of performing tasks not previously attainable, but which encompass a monitoring requirement by man in their utilization. Common industrial examples are the monitoring of an array of dials, gages, and similar instruments which indicate the current state (particularly deviations from the norm) of a large scale production operation; and the quality control function of observing an assembly line for defective items. In military applications, consider the monitoring of sonar, radar, and related devices; watchstanders observing the instrumentation of a ship's propulsion system; and astronauts continually scanning vast banks of indicators during space flights.

Common to each of these examples is the requirement that man perform a relatively boring, monotonous role in search of characteristically infrequent, randomly occuring deviations from some standard condition. Despite the routine nature of these duties, which are referred to as vigilance tasks, their proper accomplishment is of paramount importance to the effective utilization of their related sophisticated, expensive equipment and to the resultant success of the industrial or military operation. McGrath, Harabedian, and Buckner (1959) document in a review of the literature that man typically cannot

perform a vigilance task over extended periods of time without experiencing a decrement in performance, often as rapidly as fifteen minutes after commencing the task. This research was directed toward determining if some of man's physiological functions are correlated with his performance in a vigilance task.

II. PURPOSE

Mackworth (1950) initiated early work to formalize the study of vigilance tasks; and since then, the vigilance decrement has been studied by a host of investigators espousing a variety of theories to explain the phenomena. Frankman and Adams (1962), Jerison and Pickett (1963), and others have reviewed and capsulized the more widely accepted theories and the related experimental efforts to explain or prevent the decrement. Despite the considerable research conducted, the problem remains unsolved.

More recently there has been some interest in the relationship of physiological parameters to vigilance performance. Eason, Beardshall, and Jaffee (1965) observed the neck muscle tension level, skin conductance, and heart rate of subjects (Ss) performing a vigilance task. They found that skin conductance decreased ($p < .01$) with decreasing performance, while neck EMG increased ($p < .05$) and heart rate did not change significantly. Based on these results, they considered that a more thorough investigation to determine which of these parameters are contributing to variations in performance would be beneficial.

Andreassi, Rapisardi, and Whalen (1967) recorded the heart rate, palmar skin conductance, and galvanic skin response of four Ss performing a vigilance task. They found no significant correlation between each parameter considered and vigilance performance. Nonetheless, they theorized that physiological parameters are of potential utility in predicting vigilance performance and that the lack of correlation they observed might have been due to the restrictive experimental design employed.

The relationship between skin conductance levels and vigilance performance has also been observed by Freeman (1940), Schlosberg (1954), Schlosberg and Kling (1959), Ross, Dardano and Hackman (1959), Dardano (1962), and Andreassi (1966). The correlation observed by Freeman and Schlosberg was not replicated by Schlosberg and Kling, using a larger sample. Ross, Dardano, and Hackman found a relationship, though a non-significant one, between high performance on the famous Mackworth clock test and skin conductance. Dardano advocates the existence of a critical level of skin conductance above which efficient vigilance performance can be sustained. Further, a significant relationship between detection reaction time and skin conductance was reported by Andreassi.

In addition to the observance of skin potential responses by Andreassi, Rapisardi and Whalen (1967), the parameter was also studied during a vigilance task by Surwillo and Quilter (1965). They found that, for correctly observed signals, Ss had a greater number of skin potential responses immediately prior to signal presentation.

Kibler (1968) monitored the heart rate of 36 Ss reporting the occasional brighter flashes of a blinking light. He reports that the rank order correlations relating detection efficiency and median heart rate in successive quarters of a 96 minute task were low and insignificant. The heart rate preceding a stimulus event decelerated.

Thus there is evidence of significant and conjectured correlation between various physiological parameters and vigilance, although there are also contradictory reports indicating no significant relationship was present. In total, these investigations constitute but a small portion of the extensive overall research of the vigilance decrement, and appear to be insufficient to as yet establish or deny the utility

of these parameters in eventual applications to improve vigilance performance. Only recently, Randel (1968) suggests that, based on a review of current knowledge, such physiological monitoring should be extended. Further, she suggests that, after identifying periods of ineffective physiological activity, external stimulation could be employed to re-establish desired activation levels in order to improve performance.

Interestingly, although it is known that interactions do exist in the human body, review of the literature reveals no application of a multivariate analysis to the relationship between combinations of physiological parameters and vigilance performance. It seems reasonable to hypothesize that such an approach might identify some complex interactions among these parameters and performance during a monitoring task.

Accordingly, it was the purpose of the present research to consider such a relationship using heart rate, skin resistance, blood pressure, and skin temperature observations. To that end, each parameter was recorded during a 48 minute vigil with the resulting data subjected to a multivariate analysis. Should this process identify parameters directly correlated with vigilance performance, further study for the eventual determination of means to stabilize such correlates at the levels observed during good performance would be the next logical step. Such an approach is in consonance with the widely supported Arousal Theory advocated by Hebb (1955), who asserts that a variety of input sensations are required to stimulate cortical activity during a vigilance task in order to maintain responsiveness at an optimal level, thus countering the inherent monotony experienced by the observer.

It would be desirable to record and analyze data on a wider range of physiological parameters, to include, in addition to those studied herein,

brain waves (EEG), electrocardiogram (ECG), electromyogram (EMG), and eye movements (EOG). Still other parameters could be introduced, including certain environmental parameters. This research was constrained in scope by availability of equipment and time and should be considered only as a pilot study for a more comprehensive investigation. A large portion of this effort concerned the accumulation, organization, and checkout of the necessary measurement equipment. The establishment of a functioning vigilance task laboratory at the Naval Postgraduate School, which can be used and expanded by future human factors investigators, is not the least of the fruits of the present research.

III. METHOD

To simulate a vigilance task, a voltmeter test similar to that described in Wiener (1964) was used. Subjects were required to observe for 48 minutes a voltmeter needle which was programmed to make 50 deflections per minute. All but 32 of a total of 2400 deflections were of a constant magnitude considered to be the normal deflection. The remaining 32 deflections were of a constant but greater magnitude and were referred to as the "signal" to be detected by the subject.

A table of uniformly distributed random numbers was used to schedule these signals throughout the duration of the experiment, with the modification that eight signals were caused to occur during each of the four 12 minute test segments. The experimenter (E) was prepared to further modify the scheduling process to ensure that a minimum intersignal interval of 20 seconds was present, but the initial random schedule provided this interval without modification.

The difference in magnitude between a normal needle deflection and the signal was determined in preliminary experimentation during which the difference was adjusted until Ss in pilot runs experienced difficulty in maintaining a high level of detection proficiency over time. Subjects indicated the detection of a signal by pushing the button of a hand held switch, which when depressed recorded the response graphically. A response within 2.5 seconds of a signal presentation was considered a detection. Other responses were designated commissive errors.

Six male military officers served as Ss. All were volunteers from among the graduate school associates of the experimenter and varied in age from 27 to 36 years. None had previously performed a related vigilance task.

A. APPARATUS

A voltmeter with a 4 inch X 3-1/2 inch face and 2-1/2 inch black needle was modified as follows to simulate a vigilance task. The scale was removed and an unmarked white background was inserted in its place. Additionally, the glass plate was removed to reduce reflections which could be used as reference points by the S. The instrument was mounted in a nearly vertical position on a sheet of plywood placed on the table on front of the seated S. In this arrangement, the voltmeter was located approximately 26 inches from the observer and at a height of about 6 inches below the S's eye level.

Paneling was erected around the S to create a booth effect and to prevent distraction by supporting equipment and movements of the E. Subjects wore an Allied H-885 headset, through which white noise was generated by a Lafayette Instrument Co. Model 14315 White Noise Generator in order to muffle equipment noise. Though some minor external noise was still discernible, there were no auditory clues to distinguish a signal from a normal needle deflection.

Systolic and diastolic blood pressure were measured at three minute intervals throughout the test employing an Air-Shields, Inc. Model S/D-1 Monitor and Model C Dia-Pump Compressor, with a Taylor Instrument Co. cuff attached to the S's left upperarm.

To detect skin resistance and heart rate, Beckman Biopotential Skin Electrodes were employed. For skin resistance, the active electrode was placed on the outside surface of the right wrist, while the ground electrode was attached to the stomach area. Several locations for the placement of the active electrode were tried in preliminary tests, including the palmar area suggested by Venebles and Martin (1967). Due to the stimulation of the left arm by the action of the blood pressure cuff, only

locations on the right arm and hand were considered. It was also necessary to use the right hand to activate the detection indicator switch, again due to the measurement of blood pressure on the left arm and a requirement that the left arm and hand remain motionless during the recording of blood pressure to ensure proper functioning of the monitor. The process of holding the switch, and the action of depressing its button in response to signals, changed the pressure of the electrode's contact with the skin when placed in the palmar area. This affected the resistance recorded and thus rendered the palmar area unsuitable. The wrist, though not as populated with active sweat glands as the palmar area, was found to be a reliable location which ensured a constant contact with the skin and avoided conflict with other measurement devices.

Three electrodes were required to record the heart beat: one placed over the left breast, one below the right breast, and a ground attached to the stomach area. A single Yellow Springs 400 Series Thermistor was used to indicate skin temperature, placed on the outside surface of the upper right arm. The selection of this location for the thermistor was again determined after trials on several surface areas. The upper arm was chosen primarily for convenience, as other measurement devices were avoided and it provided a smooth surface for a reliable contact between skin and thermistor.

Prior to the placing of heart rate and both ground electrodes, the skin was cleaned using rubbing alcohol. Beckman Offner paste was inserted in each electrode before use to improve the contact. Electrodes were held securely in place on the skin by Beckman adhesive paper applicators.

To translate the physiological inputs detected by the skin electrodes (or thermistor in the case of skin temperature) into continuous graphical

outputs, a six pen Edin Co. Oscillograph Recorder was used. The voltage inputs to recorder pens were products of locally designed circuitry incorporating the electrodes and thermistor and Brush Electronics Co. Dual Channel D. C. Amplifiers. The latter provided a scale and sensitivity control for each oscillograph recorder pen.

Circuitry for skin temperature included a Wheatstone bridge (of which the thermistor was a component), whose output was channeled through an integrated circuit operational amplifier to the Brush amplifier. To measure skin resistance, a small voltage was first introduced across the body via the attached electrodes. For the initial body resistance of the S, a potentiometer was employed to adjust a zero output so that all subsequent outputs reflected changes in body resistance. These voltages were multiplied by 1000 in an operational amplifier prior to entry into the Brush amplifier.

Field effect transistors, in a differential amplifier configuration, were utilized to effect noise cancellation and impedance matching during the detection of heart rate. The dual signal output of the differential amplifier was next amplified and joined as a single output by an integrated circuit operational amplifier, from which the signal was fed into the Brush amplifier.

The schedule of needle deflections was programmed by E on a paper tape which, when fed through an Ohr-tronics, Inc. Model 119 Paper Tape Reader, produced an electrical pulse to the voltmeter, actuating the needle at the designated rate of 50 deflections per minute. This electrical pulse was routed over one of two circuits, depending on whether a normal deflection or a signal was programmed at each time interval. By varying the resistance in these two circuits, the desired needle deflections were predetermined.

The initiation of each signal by the paper tape reader also provided a signal to the oscillograph recorder, where a tick mark was recorded by a pen as the signal was presented. An adjacent pen recorded each detection response by the S, thus providing a means of analyzing correct detections, commissive errors, and concurrent heart rate, skin resistance, and skin temperature recordings.

B. PROCEDURE

Subjects were introduced to the laboratory by directing them to the test booth, where they were seated and asked to relax. Wrist watches were removed from the S. Detailed instructions were then read by E, including a description of the task, an explanation of the measurement devices, assurances concerning the safety of electrodes to be placed on their skin, and an outline of the test procedures they were to participate in (see Appendix A). Measuring devices were attached to the S and instrumentation was calibrated. A practice session followed during which Ss were again briefed concerning the task to be performed and a sample program of normal and abnormal needle deflections was presented. Sufficient time was allowed to ensure that each S was thoroughly familiar with his duties before commencing the test. Lastly, the headset was placed on the S and adjusted to a comfortable fit, and the test commenced.

C. REDUCTION OF DATA

At the conclusion of experimentation, a continuous trace of each S's skin temperature, heart rate, and skin resistance, along with a record of each signal presented and all the S's responses, were available on oscillograph paper. In addition, a record of the systolic and diastolic blood pressure readings at three minute intervals had been maintained.

To reduce this data preparatory to analysis, the following procedures were applied. Skin temperature and skin resistance measures for each

signal presented were obtained by averaging the graphical record of the number of centigrade degrees and ohms, respectively, for the 15 second sample immediately preceding each signal. The number of heart beats recorded in this same 15 second interval, when multiplied by four, provided a measure of the heart rate in beats per minute prior to each signal.

D. PERFORMANCE MEASURES

The analysis of recorded data fell into two general categories. The primary effort was concerned with the relationship between detection performance and parameter measures as observed in the four 12 minute time segments. Accordingly, the percentage of detected signals during each time segment by each S was the performance measure. The skin temperature, skin resistance, and heart rate data for each of the eight signals per segment were averaged to provide a single parameter reading per segment for each S. Pulse pressure at each three minute interval was obtained by subtracting the corresponding diastolic from the systolic blood pressure readings. Average pulse pressure and systolic and diastolic blood pressure readings per time segment for each S were then found.

The second objective of the analysis was to compare skin temperature, heart rate, and skin resistance measures for detected signals versus these same parameter measures for missed signals. Thus, the performance measure here was the S's response to each signal presented.

IV. RESULTS

A graphical representation of the behavior of each of the six observed physiological parameters versus detection percentage over the four 12 minute time segments is depicted in Figures 1, 2, and 3 for all Ss combined together. A two way analysis of variance was performed on each parameter and on detection percentage to test for significant differences between time segments using the model shown in Table I.

Table I. Analysis of Variance Model

Source	Degrees of Freedom
Subjects	5
Time Segments	3
Error	15
Total	23

In the case of detection percentage in this and subsequent analyses, an arcsin transformation to radians was first made in order to obtain homogenity of error variance and to justify the additivity of effects stipulated by the ANOVA model, as suggested by Winer (1962).

The results of these ANOVA's are shown in Tables II through VIII. Skin temperature, $F(3,15) = 2.50$, $p < .10$; heart rate, $F(3,15) = 3.58$, $p < .05$; and systolic blood pressure, $F(3,15) = 2.86$, $p < .10$, where the only parameters found to differ between time segments for any acceptable level of significance.

The next step in the analysis was to determine if any relationship existed between individual parameters and detection performance over time segments. A simple linear correlation analysis was computed for

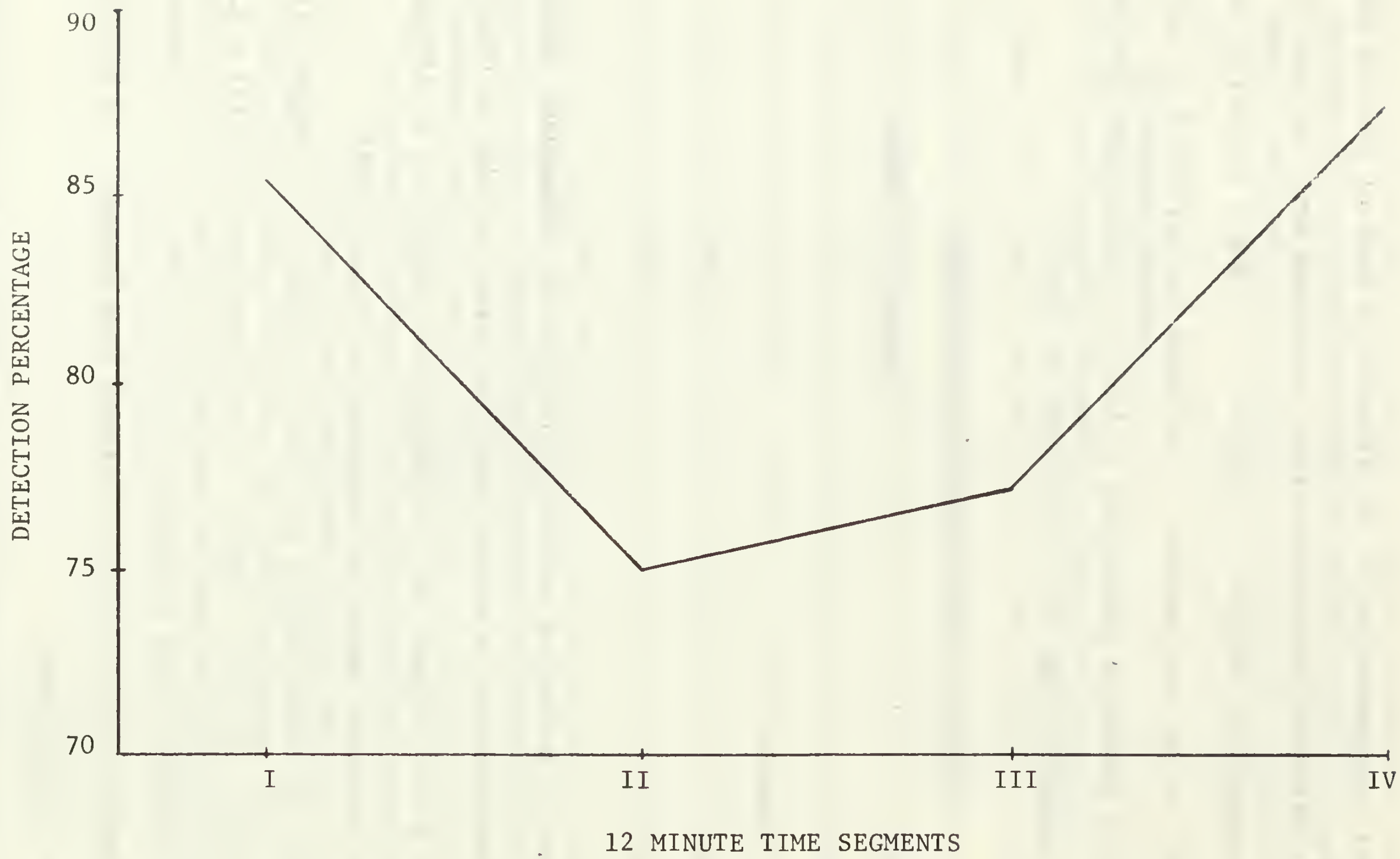

FIG. 1 DETECTION PERCENTAGE VS 12 MINUTE TIME SEGMENTS

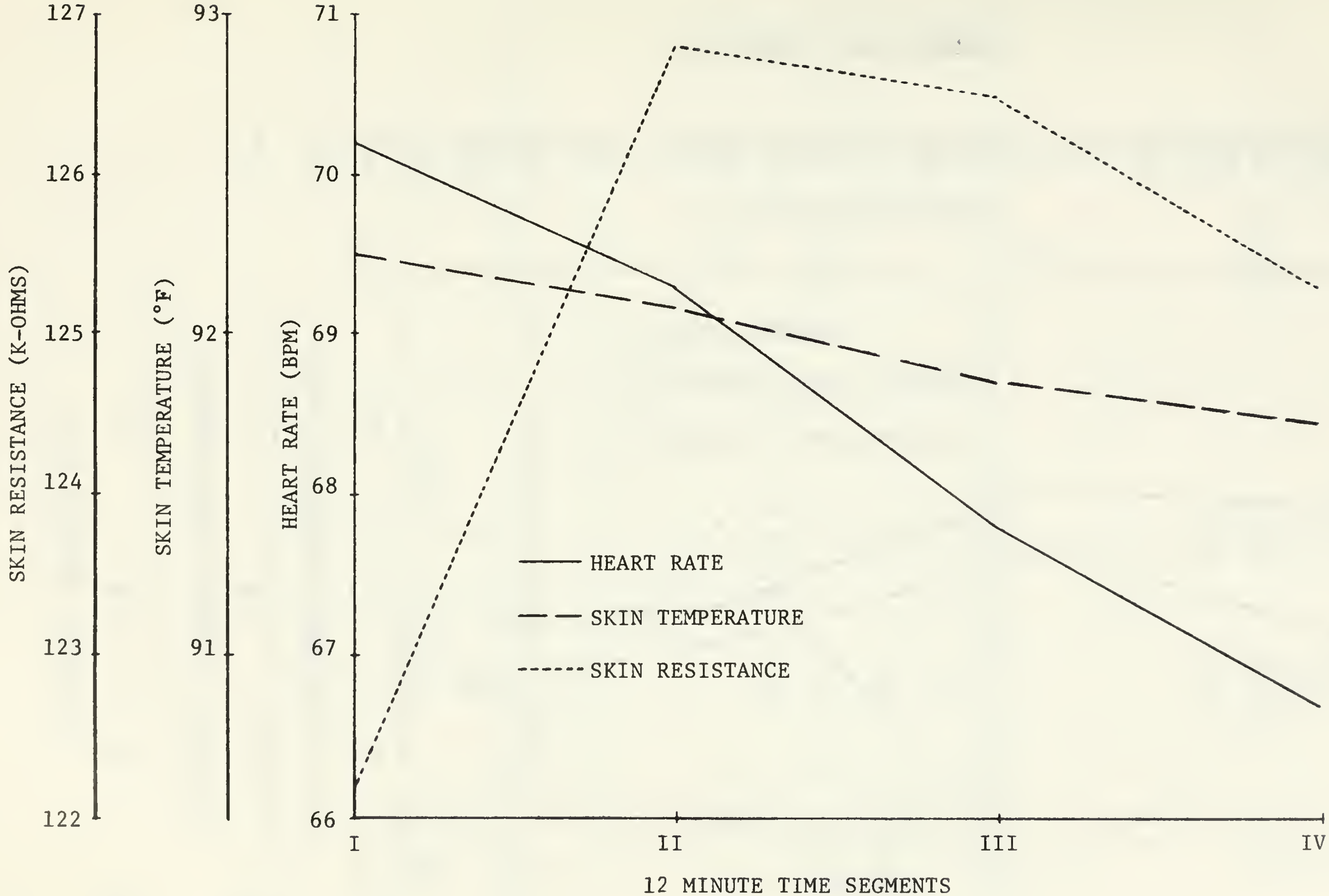

FIG. 2 HEART RATE, SKIN TEMPERATURE, AND SKIN RESISTANCE VS 12 MINUTE TIME SEGMENTS

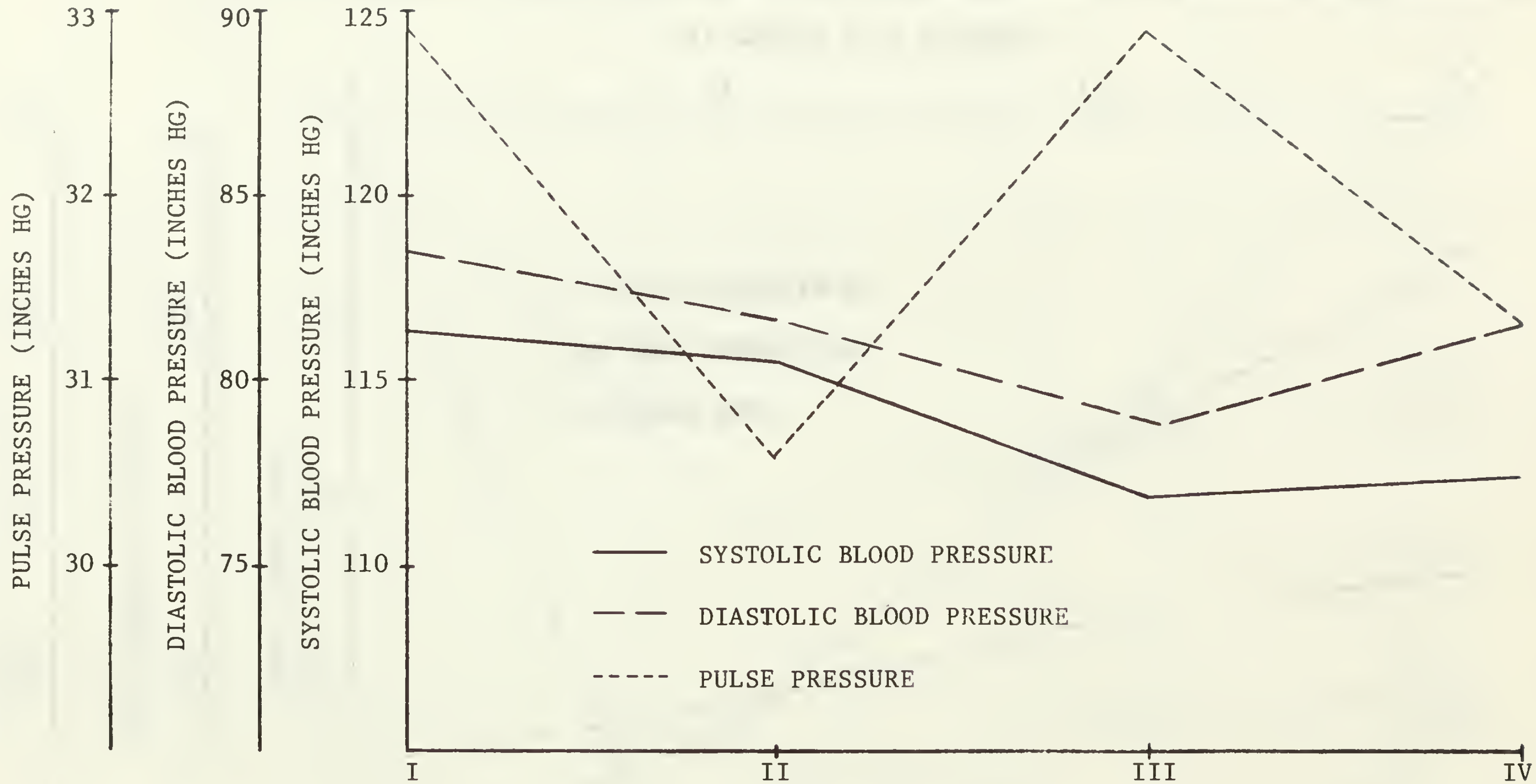

FIG. 3 SYSTOLIC BLOOD PRESSURE, DIASTOLIC BLOOD PRESSURE, AND PULSE PRESSURE

VS

12 MINUTE TIME SEGMENTS

Table II. Analysis of Variance on Arcsin Transformation of Percentage of Detections

Source	df	SS	MS	F
Subjects	5	3.30	0.66	2.28*
Time Segments	3	0.79	0.26	0.92
Error	15	4.33	0.29	
Total	23			

*$p < .10$

Table III. Analysis of Variance on Skin Temperature (°C)

Source	df	SS	MS	F
Subjects	5	17.49	3.50	64.59*
Time Segments	3	0.0	0.14	2.50**
Error	15	0.81	0.05	
Total	23			

*$p < .001$
**$p < .10$

Table IV. Analysis of Variance on Skin Resistance (k-ohms)

Source	df	SS	MS	F
Subjects	5	214380.37	42876.07	62.28*
Time Segments	3	81.75	27.25	0.04
Error	15	10326.38	668.42	
Total	23			

*$p < .001$

Table V. Analysis of Variance on Heart Rate (bpm)

Source	df	SS	MS	F
Subjects	5	2087.62	417.52	97.38*
Time Segments	3	46.06	15.35	3.58**
Error	15	64.31	4.29	
Total	23			

*$p < .001$
**$p < .05$

Table VI. Analysis of Variance on Systolic Blood Pressure (inches H_g)

Source	df	SS	MS	F
Subjects	5	2328.81	465.76	48.66*
Time Segments	3	82.12	27.38	2.86**
Error	15	143.56	9.75	
Total	23			

*$p < .001$
**$p < .10$

Table VII. Analysis of Variance on Diastolic Blood Pressure (inches H_g)

Source	df	SS	MS	F
Subjects	5	1454.56	290.91	24.79*
Time Segments	3	57.88	19.29	1.64
Error	15	176.00	11.73	
Total	23			

*$p < .001$

Table VIII. Analysis of Variance on Pulse Pressure (inches H_g)

Source	df	SS	MS	F
Subjects	5	2303.52	460.70	14.42*
Time Segments	3	25.34	8.44	0.26
Error	15	479.06	31.94	
Total	23			

*$p < .001$

each parameter, with detection performance as the dependent variable. Linear correlation coefficients (r) and t test results (of the null hypothesis that a correlation coefficient is zero) are recorded in Table IX. Systolic blood pressure, $t(22) = 1.94$, $p < .08$; skin temperature, $t(22) = 1.92$, $p < .08$; and diastolic blood pressure, $t(22) = 1.64$, $p < .13$, were found to have some relationship with detection performances with respective r values of .382, .378, and .330.

Table IX. Results of Simple Linear Correlation Analysis, With Detection Performance as Dependent Variable

Independent Variable	Linear Correlation Coefficient (r)	Significance Level (p)
Systolic Blood Pressure (inches H_g)	.382	.08
Skin Temperature (°C)	.378	.08
Diastolic Blood Pressure (inches H_g)	.330	.13
Heart Rate (bpm)	.192	--
Skin Resistance (k-ohms)	.036	--
Pulse Pressure (inches H_g)	.069	--

To check the possibility that various combinations of physiological parameters might collectively be correlated with monitoring performance, a multiple correlation analysis was performed. Systolic blood pressure

and skin temperature were found to have the highest multiple correlation coefficient ($\underline{R}$ = .497, $\underline{p} < .06$) among all possible pairwise combinations of correlates of detection performance. The effect on the multiple correlation coefficient of adding a third variable to the analysis was next investigated, and pulse pressure was observed to provide the greatest further increase in the degree of association between variables and detection performance ($\underline{R}$ = .541, $\underline{p} < .08$). A continuation of this procedure for additional variables provided only a negligible improvement in the multiple correlation coefficient.

To compare parameter measures for detected versus missed signals, $\underline{t}$ tests (of the null hypotheses that there were no differences between parameter mean values for detected versus missed signals) were performed. A summary of these tests is depicted in Table X. The significantly lower mean skin temperature ($\underline{t}$ (190) = 2.78, $\underline{p} < .01$) for missed signals implies that performance might be improved by altering environmental conditions to maintain higher skin temperatures. No significant differences in heart rate and skin temperature were found. Since it was not possible to obtain any of the blood pressure type readings on a continuing basis, they were excluded from this analysis.

Table X. A Comparison of Parameter Measures for Detected and Missed Signals

Parameter	156 Detected Signals Mean	156 Detected Signals Std. Dev.	36 Missed Signals Mean	36 Missed Signals Std. Dev.	t
Skin Temperature (°C)	33.410	0.859	32.965	0.927	2.78*
Skin Resistance (k-ohms)	127.470	99.405	115.272	87.961	0.72
Heart Rate (bpm)	68.744	10.359	67.444	8.875	0.70

*$\underline{p} < .01$

A total of only four commissive errors were committed, distributed among three of the six Ss. Due to the relative infrequency of these errors, they were not considered in these analyses.

V. DISCUSSION

Some evidence of simple correlation between individual physiological parameters considered and detection performance was produced by this research, while the multivariate portion of the analysis provided higher significant correlations. Combinations of physiological parameters, which were found to correlate with performance, can also be considered as indicants of the S's level of arousal. Thus, support for the Arousal Theory seems to be inferred.

An examination of the data outside the formal statistical analysis already presented further substantiates these results, and provides a basis for making some additional inferences of correlation between physiological parameters and performance. Consider, for example, the behavior of the average detection percentage depicted in Figure 1. As anticipated in a vigilance task, this percentage declined in time segments II and III. However, the return to initial detection proficiency during time segment IV would appear to be contrary to expected results. Deese (1955) explains such improvement in the context of his Expectancy Theory of vigilance. Here Ss performed without specific knowledge of the cumulative or terminal time of their vigil, although they were informed prior to commencing their task that its duration was approximately one hour. Over this relatively short time period, it is possible to estimate the elapsed time with some success and each subject could be expected to either, consciously or subconsciously, anticipate the termination of his task. This anticipation could serve to remotivate the S, thereby increasing his ability to detect signals. Remotivation does not necessarily imply rearousal and it is conjecture whether or not various physiological parameters correlate with improved performance near the end of a vigil.

In the present research, systolic and diastolic blood pressures tended to observe a similar pattern of changes over time segments as did detection performance; while skin temperature and heart rate were downward trending during the vigil. (The behavior of skin resistance will be discussed in detail later.) Thus to suggest that remotivation without rearousal accounts for improved end of vigil performance implies that decreasing skin temperature and heart rate are, in some sense, indicators of declining physiological activity and concurrent declining vigilance performance.

Recalling that it was the purpose of this investigation to search for correlates of vigilance performance so that the latter might eventually be improved, a reasonable procedure here might be to observe detection performance during any portion of the vigil, in order that all possible inferences contained in the collected data might be examined. Pursuing this line of reasoning, E analyzed the relationship between detection percentage and all observed parameters over the first three time segments only.

As in the analysis over the entire test period, systolic blood pressure was the highest single correlate with performance, $\underline{r} = .417$, $\underline{p} < .09$. However, skin resistance was now found to provide, in combination with systolic blood pressure, the highest pairwise correlation coefficient, $\underline{R} = .557$, $\underline{p} < .07$, replacing skin temperature. The latter parameter became the third variable in the combinatorial procedure to improve the correlation coefficient, providing $\underline{R} = .668$, $\underline{p} < .04$. The inclusion of additional variables failed, as before, to increase the multiple correlation coefficient significantly. These results are an improvement over the parallel analysis of all four time segments, and can be interpreted

as lending additional support to the possibility of underlying correlation between complex physiological interactions in the body and vigilance performance. Certainly the decreasing trend of these parameters is at least in the same direction as is vigilance performance over time.

An inherent difficulty attendant to physiological monitoring is the wide variation in parameter values found among people. In the present research, both the differences in basal skin resistance and the ranges of skin resistance values observed over time had a distorting effect on the experimental results. Specifically, four of the six Ss had monotonically decreasing skin resistance, while one of the two remaining Ss experienced a total increase of only 3.9 k-ohms. Yet, the increasing skin resistance for the sixth S so dominated the overall average values that Figure 2 indicates an increase in skin resistance from segment I to segment II, followed by approximately constant values for segments III and IV. This S's counter trending 121.3 k-ohm range is in sharp contrast to the 20.6, 3.9, 13.7, 32.3, and 39.7 k-ohm ranges of the other five Ss.

Further, changes in skin resistance during the course of the vigil for three Ss with basal values greater than 150 k-ohms were larger than the changes of the other three Ss with basal values of 20-60 k-ohms. Data of this nature can effectively conceal a meaningful result or trend. For a closer examination of these observations, refer to Appendix B.

As shown in Table IV, there was no significant difference in skin resistance between time periods. A similar test, which did not include the S with the exceptionally wide range of values referred to earlier, did yield a significant difference, $F(3, 12) = 6.80$, $p < .01$. However, a simple correlation analysis (of detection performance and skin resistance) using this reduced sample returned an approximately zero correlation coefficient.

In a more extensive investigation of physiological correlates, a larger sample size and a longer vigil are recommended. Since a few, or even a single, individual can distort an analysis and mask the true interpretation of results, increasing the size of the sample is particularly important in experimentation of this type.

By lengthening the duration of the vigil, the range of arousal conditions might be similarly increased, thereby providing a more fertile opportunity for significant physiological correlates to be observed. A similar result might be achieved by decreasing the signal presentation rate. Baker (1958, 1959) has demonstrated that decrement levels are related to intersignal intervals. In a simulated PPI scope display, he observed no decrement for an intersignal interval of 36-196 seconds; while a later replication, using an intersignal interval of 45-645 seconds, resulted in a performance decrement. In the current experiment the intersignal interval varied from 27 to 215 seconds.

The investigation of physiological parameters in search of correlates of vigilance performance is a relatively unexplored region within the body of vigilance knowledge. Experimentation of this type is tedious, requires expensive and unique measuring devices, and is highly sensitive to experimental conditions and design. Attempts to simultaneously observe the more sophisticated parameters, such as brain waves, electrocardiogram, and electromyogram, present formidable obstacles. The ever increasing relegation of man to the role of monitoring complex, expensive, and operationally important equipment should, however, provide the necessary impetus to extend the investigation of these and other physiological parameters.

APPENDIX A INSTRUCTIONS

Please relax and listen closely as I read your instructions. You are going to be asked to carefully observe the movement of the needle in the instrument mounted on the board to your direct front. Specifically, your task will be to distinguish between normal and less frequent abnormal needle deflections and to record only abnormal deflections by pressing the counting device on the table in front of you, using your right hand. I will demonstrate the difference between the two deflections. You will have to remain attentive in order to avoid missing abnormal deflections or recording normal deflections as abnormal ones.

While you are performing this task, I will be recording physiological readings. Accordingly, small, completely harmless electrodes will be placed on your skin and a blood pressure cuff will be attached to your left arm. There is absolutely no possibility that you will receive an electrical shock or otherwise be harmed by these measuring devices. Please do not move your left arm and avoid abrupt movement of your upper body during the experiment to ensure that the measuring devices function properly.

I will now attach the electrodes and blood pressure cuff to your body, to be followed by a demonstration of normal and abnormal needle deflections. During this time you have a chance to practice your task of observing and recording abnormal deflections. Please note, however, that the rate at which these abnormal deflections will appear during your practice period is faster than the rate at which they will actually appear during the experiment.

We will not commence the experiment until you are satisfied that you understand these instructions and the task you are to perform. Do you have any questions?

APPENDIX B SUMMARY OF OBSERVED DATA

Parameter	Segment	Subjects 1	2	3	4	5	6
Skin Temp. (°C)	I	32.04	33.95	34.70	32.90	33.24	34.03
	II	32.09	33.50	34.82	32.75	33.23	33.89
	III	32.19	33.13	34.93	32.58	33.19	33.54
	IV	32.28	32.80	35.04	32.49	33.14	33.34
Skin Resist. (k-ohm)	I	61.2	19.8	45.4	171.8	240.8	193.9
	II	52.8	20.9	38.6	163.9	225.0	259.8
	III	44.2	22.5	37.0	150.8	209.2	295.2
	IV	40.6	23.7	31.7	139.5	201.2	315.2
Heart Rate (bpm)	I	76.5	79.5	81.5	62.5	67.5	54.0
	II	72.0	82.5	79.0	60.5	65.5	56.5
	III	67.0	82.0	77.5	62.0	63.5	54.5
	IV	68.5	80.5	76.0	60.0	60.5	54.5
Systolic BP (inches H_g)	I	114.8	128.8	115.4	111.0	126.0	101.2
	II	108.6	129.6	118.4	111.2	124.8	101.0
	III	102.8	128.6	116.2	108.6	120.4	94.6
	IV	101.6	130.0	115.4	104.2	120.4	104.4
Diastolic BP (inches H_g)	I	74.0	97.6	75.6	76.4	81.2	94.8
	II	74.4	100.0	77.8	72.4	79.0	86.6
	III	72.6	85.4	79.2	73.8	77.6	85.0
	IV	70.6	91.6	80.2	73.6	79.0	93.2
Pulse Pressure (inches H_g)	I	40.8	31.2	39.8	34.6	44.8	6.4
	II	34.2	29.6	40.6	38.8	25.8	14.4
	III	30.2	43.2	37.0	34.8	42.8	9.4
	IV	31.0	38.4	35.2	30.6	41.4	11.2

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DOCUMENT CONTROL DATA - R & D

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1. ORIGINATING ACTIVITY *(Corporate author)* Naval Postgraduate School Monterey, California	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

An Investigation of Physiological Correlates of Vigilance Performance

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Master's Thesis

5. AUTHOR(S) *(First name, middle initial, last name)*

James Hager Tinsley

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
October 1969	38	24

8a. CONTRACT OR GRANT NO. b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Naval Postgraduate School Monterey, California 93940

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A pilot investigation of physiological parameters was conducted to determine possible correlates of vigilance performance. Six parameter measurements were continuously recorded during a forty-eight minute vigil as six subjects monitored a voltmeter display. Simple and multiple linear correlation analyses were performed to determine the relationship between parameters observed and the percentage of signals detected. Results showed systolic blood pressure ($\underline{r}$ = .382, $\underline{p} < .08$), skin temperature ($\underline{r}$ = .378, $\underline{p} < .08$), and diastolic blood pressure ($\underline{r}$ = .330, $\underline{p} < .13$) were each correlated with vigilance performance. No correlation was found between performance and skin resistance, heart rate, or pulse pressure. A multivariate analysis indicated that the addition of skin temperature to systolic blood pressure provided a multiple correlation of $\underline{R}$ = .497, $\underline{p} < .06$, between those parameters and performance, and the further addition of pulse pressure as a third variable increased $\underline{R}$ to .541, $\underline{p} < .08$. These results and some additional, ad hoc analyses are interpreted in the context of the Arousal Theory of vigilance.

Security Classification

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	ROLE	WT	ROLE	WT	ROLE	WT
Vigilance						
Monitoring						
Heart Rate						
Skin Temperature						
Skin Resistance						
Blood Pressure						

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DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6811

Security Classification

A-31408

Security Classification

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Vigilance						
Monitoring						
Heart Rate						
Skin Temperature						
Skin Resistance						
Blood Pressure						